**BEAM TRANSFER FUNCTION MEASUREMENTS OF THE PEP II
TRANSVERSE DAMPER SYSTEMS**
Dave McGinnis
September 18, 1997

<u>Introduction</u>

This paper is a brief writeup of the beam transfer function (BTF) measurements that were made on the PEP II transverse damper systems on the OWL Shift of September 16, 1997. A simple schematic of the damper systems is shown in Figure 1.
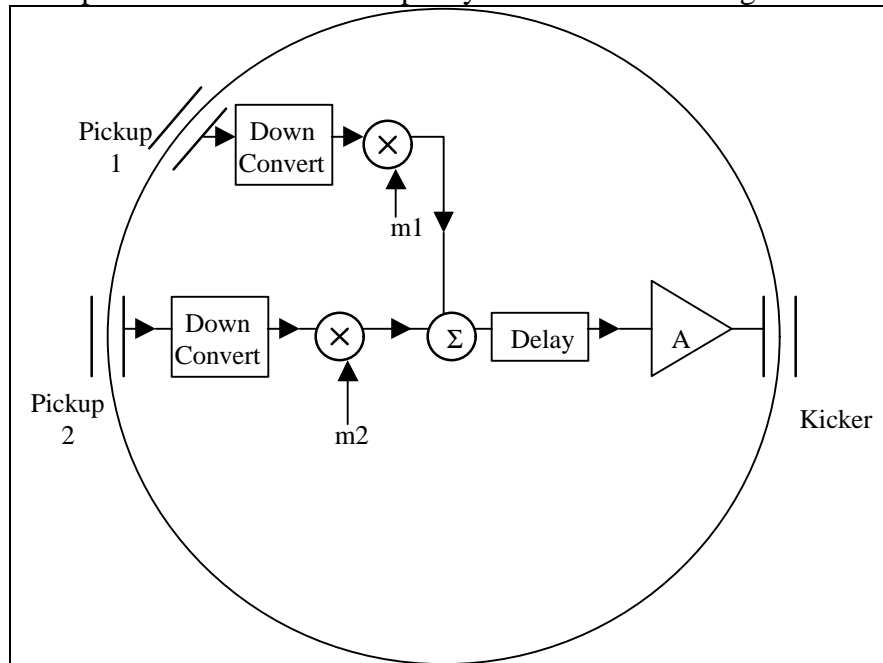

Figure 1. A simple schematic of the PEP II Transverse Damper Systems

The variable multipliers on the two pickups of the damper system are used to obtain the ideal betatron phase advance between the pickups and kickers. The betatron phase advance between the two pickups is on the order of 90 degrees. The net effect of changing the ratio of the multipliers is to create a virtual pickup between the two pickups in which the betatron phase advance between the virtual pickup and the kicker is an odd multiple of 90 degrees.

The RF signal on the pickups is down converted to baseband. The signal processing (which is mainly the digital delay) is done with an analog bandwidth of approximately 250 MHz. After the signal has been processed, it is power amplified at baseband to take advantage of the stronger field of a transverse kicker at low frequencies. Therefore, the power amplifier spans a bandwidth from about 20 kHz to 250 MHz.

The damper system configured for beam transfer function measurements is shown in Figure 2. A network analyzer is inserted in the damper chain just before the power amplifier. The network analyzer sends out a sine wave at a given frequency to the kicker.

The kicker modulates the beam current at this frequency. The pickup detects this wave and the amplitude and the phase is compared to the amplitude and phase of the wave at the kicker. This measurement is then swept over a band of frequencies.
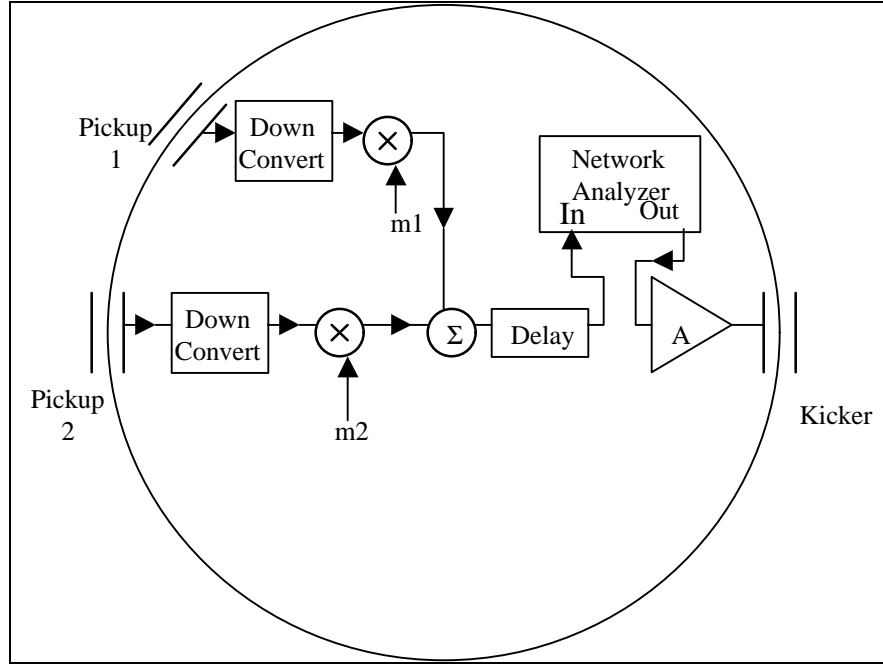

Figure 2. Damper system configured for a beam transfer function measurement.

A simplified block transfer function diagram of a damper system is shown in Figure 3. The damper system can be thought of as an impedance Z where a current signal detected on the pickup is applied as a voltage on the kicker. The beam can be thought of as a conductance where a voltage applied to the beam modulates the beam current distribution.
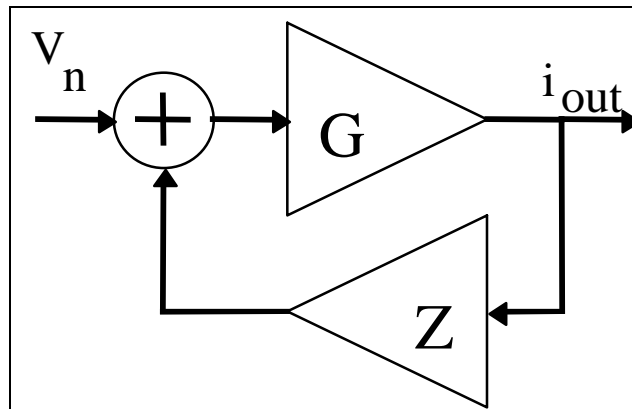

Figure 3. Block transfer function diagram of a damper system.

A voltage applied to the beam will modulate the beam current:

$$i_{out}(s) = G(s)\big(v_{in}(s) + Z(s)i_{out}(s)\big) \tag{1}$$

where:

$$v(t) = v(s)e^{st} = v(\sigma + j\omega)e^{(\sigma + j\omega)t} \tag{2}$$

Equation (1) becomes:

$$i_{out}(s) = \frac{G(s)}{1 - Z(s)G(s)}v_{in}(s) \tag{3}$$

For stability, the real part of the poles of the transfer function described in Equation 3 must be less than zero. Therefore:

$$Re\{Z(s)G(s)\} < 1 \tag{4}$$

The product $Z(s)G(s)$ is just the open loop gain measured by the beam transfer function outlined in Figure 2.

Measurements

The PEP II HER was filled with a symmetric pattern of 36 bunches out of a total possible 3192 and the beam current ranged from 20-50 mA. The network analyzer was inserted into the feedback loop as shown in Figure 2. The output power applied to kicker amplifier was on the order of -36 dBm. The IF(intermediate frequency) bandwidth of the network analyzer was set to 20 Hz. **It is important to note** that because of the large size of extraneous coherent oscillations on the beam (presumably due to noise on the magnet bus and the RF system) that the IF bandwidth of the network analyzer should be kept as low as possible. Because the network analyzer makes vector measurements, a lower IF bandwidth will allow the analyzer to "average" away these extraneous oscillations from the BTF measurements better than a wide IF bandwidth.

An actual beam transfer function using the vertical system is shown in Figures 4 and 5. Figure 4 shows the response at the very lowest betatron sideband (1-Q if the tune is below the 1/2 integer) and Figure 5 is the 1+Q response. Since the damper digitizer is sampling at every bucket but there is only 36 bunches in the ring, the beam transfer function response must be multiplied by a factor of 3192/36 = 89 (39 dB). This means that the most positive peak of the Real Part of the BTF in Figure 4 is actually 10.4 which is much greater than +1 criterion outlined in Equation 4. Thus, the damper will be unstable for beam currents over 0.1 mA per bunch. One can determine how much out of phase the damper is by adjusting the phase offset knob on the network analyzer until the positive going peaks on the real part of the BTF is removed and is symmetric looking. For Figure 4, the amount of phase needed to add is 80 degrees. Figure 5 is the 1+Q line BTF response. The amount of phase needed to add is -40 degrees. If the betatron phase advance between the virtual pickup and the kicker is an odd multiple of 90 degrees, the phase difference between the upper and lower sidebands around a single revolution line would be zero. The difference in phase between the upper and lower sidebands of a single revolution line is equal to twice the error in betatron phase advance. Thus the error in betatron phase advance for Figures 4 and 5 is 60 degrees. The average of the phase error in Figures 4 and 5 is +20 degrees. Assuming that the delay of the damper is correct, this 20 degrees is probably due to the phase roll at the low end of the power amplifier frequency band.

Figures 6 and 7 show the vertical BTF around the 73rd harmonic. The phase needed to add to remove positive going peaks in the real part in Figure 6 is +60 degrees and the phase needed to add in Figure 7 is -60 degrees. Thus the error in betatron phase advance is 60 degrees with zero error in the phase intercept of the damper system.

To remove the error in betatron phase advance, the BTF far away from the power amplifier roll off should be measured. It seems that the 73rd harmonic is sufficient. Then one of the multipliers on the pickups should be set to zero. In the case of Figure 8, it was the y1 multiplier. The other multiplier (y2) should be kept at a constant 5.0V. While observing the real part of the BTF of the 73-Q betatron line, the previously zeroed multiplier (y1) should be varied until the Real part of the BTF looks symmetric and negative. This occurred for y1=+0.1V. This procedure should then be repeated at the 73+Q line. The value needed for y1 = -0.1V. The correct value for y1 should be the average of the two measurements, which turned out to be 0.0V in this case. It appears from these measurements that the phase advance from pickup 2 and the kicker is very close to and odd multiple of 90 degrees. If the delay or the phase intercept of the damper system is perfect, then the two measurements for the optimum value of y1 should have been the same. The difference of 0.1V is small enough to be neglected. The BTF around the 73rd harmonic with the new multiplier values is shown in Figures 8 and 9.

Now that the betatron phase advance of the damper system has been optimized, the small signal damping rate can be determined. Using simple resonator theory, the damping time of the damper is given by:

$$\tau = \frac{1}{g \cdot \Delta f}$$
(5)

where **Δf** is the width of the betatron line in the BFT response and **g** is the maximum value of the negative real part of the BTF. From Figure 8 and 9 the width of the betatron line is about 50Hz. The magnitude of the line after normalizing for duty factor is 16. The damping time would then be about 1.2 mS. This is for 0.58 mA per bunch. The damping rate will scale as the current per bunch (i.e. the damping time would be 0.7mS for 1.0mA per bunch).

With the new vertical multipliers, the BTF around the first revolution is again measured as shown in Figures 10 and 11. A +20 degree phase adjustment is needed on both sidebands to optimize the real part of the BTF. This can only be done without disturbing the phase of the higher harmonic lines by using some sort of phase equalizer. One sees that in Figure 11, that the positive going real part has a value of 4.5 after accounting for duty factor. Thus the damper will still be unstable at this line even with the new multiplier corrections. One should note that the width of the 1-Q line is much wider than the width of the 1+Q line (assuming that the tune is below the 1/2 integer). This is probably due to a fairly large value of chromaticity. So, adjusting the vertical chromaticity may reduce the problem at the 1-Q line. However, the phase roll of +20 degrees is still too large to tolerate.

Figures 12 and 13 show the horizontal BTF response with the original multiplier settings. (The squiggles on the right hand side of the plot are due to a large extraneous driven signal that was not totally averaged away by the network analyzer.) By adjusting the multipliers following the procedure outlined in the preceding paragraphs, one can find the optimum values shown in Figures 14 and 15. However, the difference in multiplier

settings between the upper and lower sideband measurements was about 1.0V. This means that there is probably a phase intercept or delay error in the damper system. One should check more sidebands but machine study time ran out.
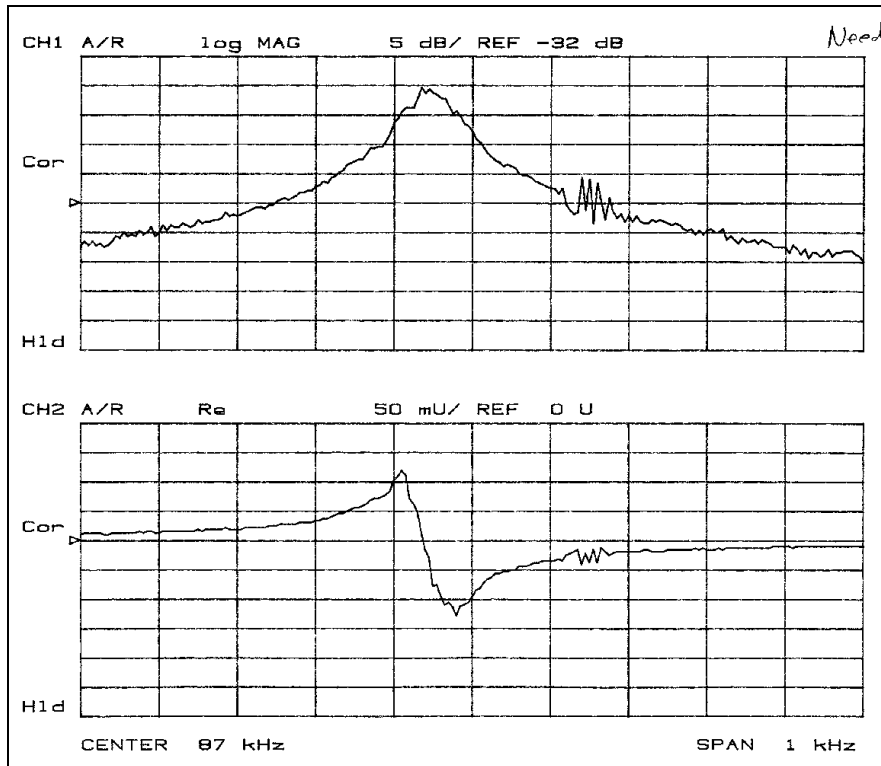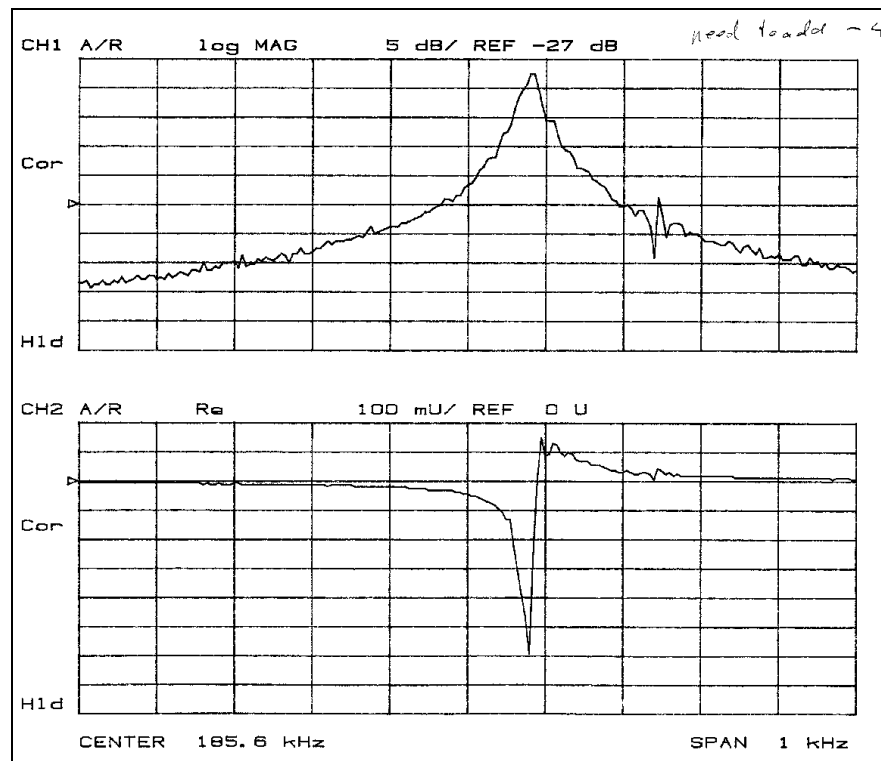
Figure 4. The beam transfer function response of the vertical damper system at the 1-Q line. There are 36 bunches at 39 mA. The multiplier settings are y1=5.25V and y2=1.6V
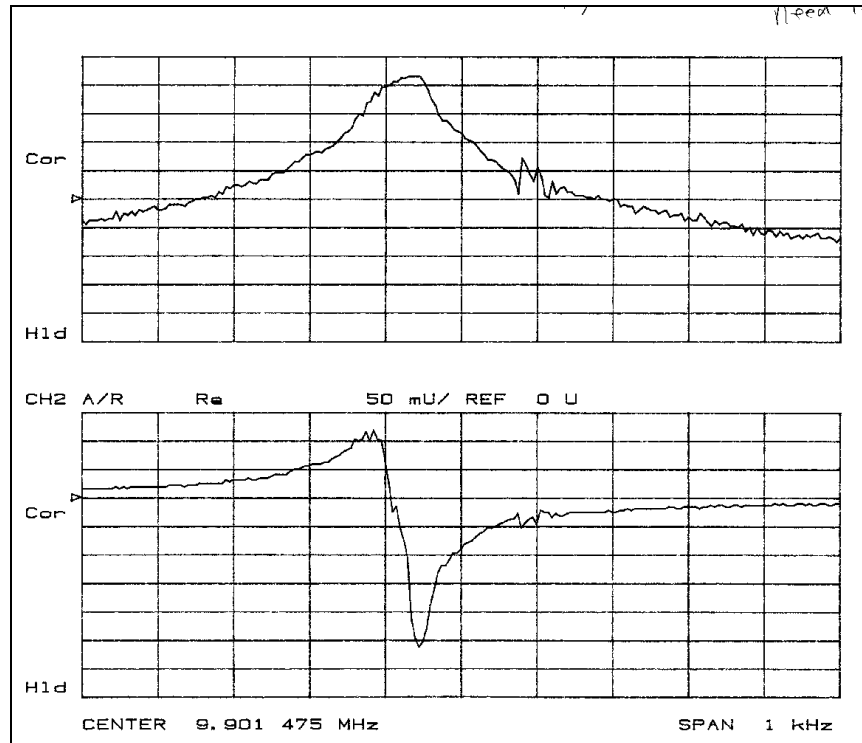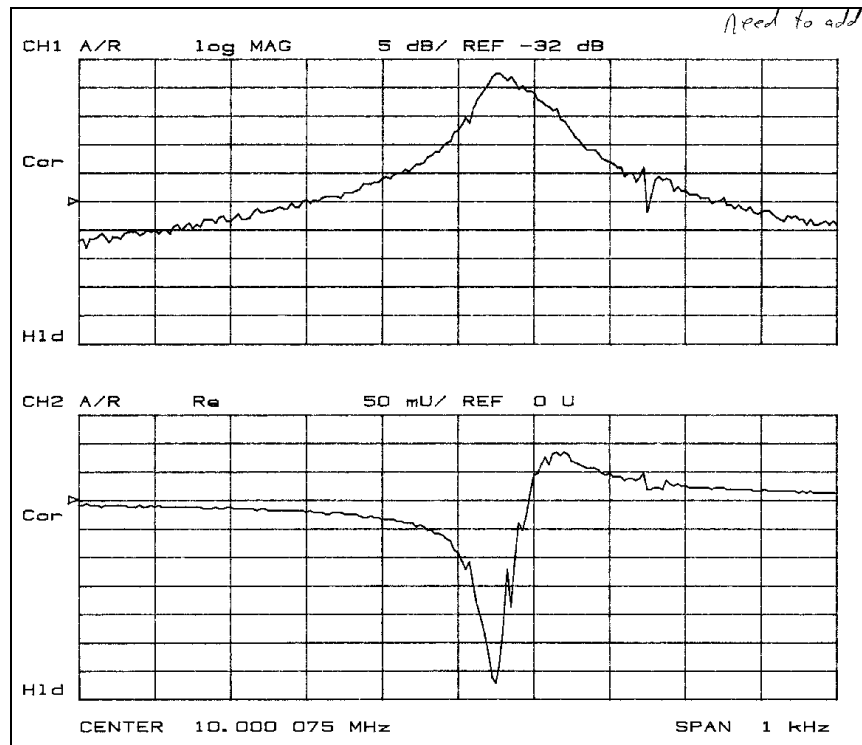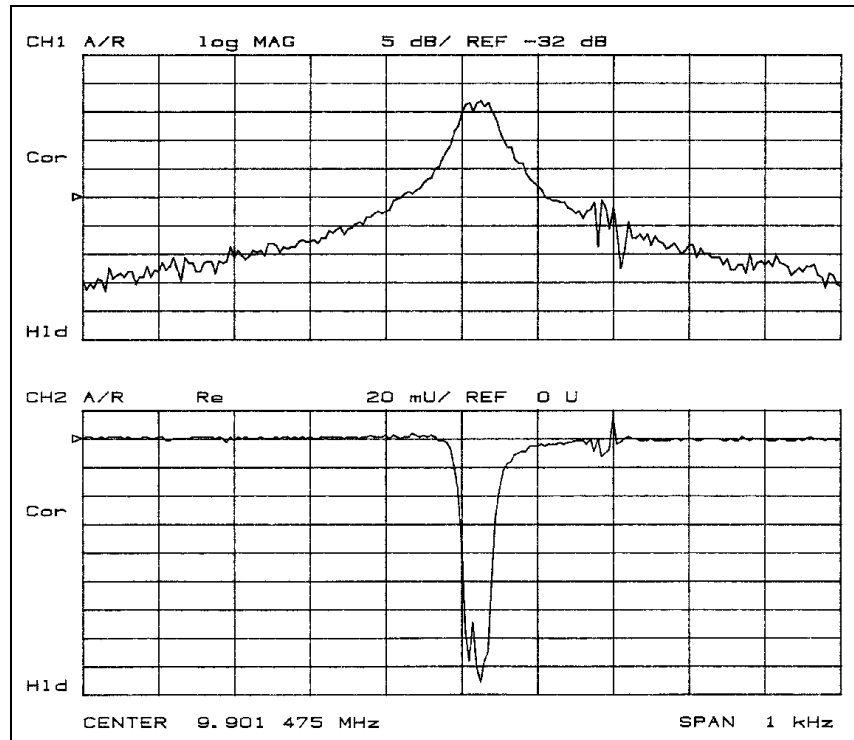

Figure 5. The beam transfer function response of the vertical damper system at the 1+Q line. There are 36 bunches at 39 mA. The multiplier settings are y1=5.25V and y2=1.6V

Figure 6. The beam transfer function response of the vertical damper system at the 73-Q line. There are 36 bunches at 47 mA. The multiplier settings are y1=5.25V and y2=1.6V
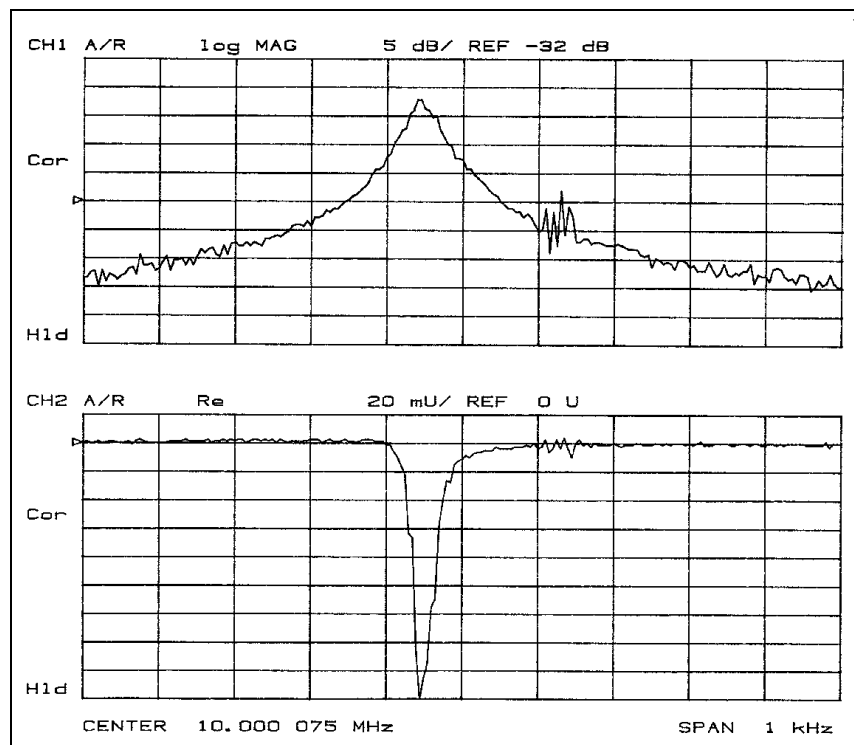

Figure 7. The beam transfer function response of the vertical damper system at the 73+Q line. There are 36 bunches at 47 mA. The multiplier settings are y1=5.25V and y2=1.6V

Figure 8. The beam transfer function response of the vertical damper system at the 73-Q line. There are 36 bunches at 21 mA. The multiplier settings are y1=0.0V and y2=5.0V

Figure 9. The beam transfer function response of the vertical damper system at the 73+Q line. There are 36 bunches at 21 mA. The multiplier settings are y1=0.0V and y2=5.0V
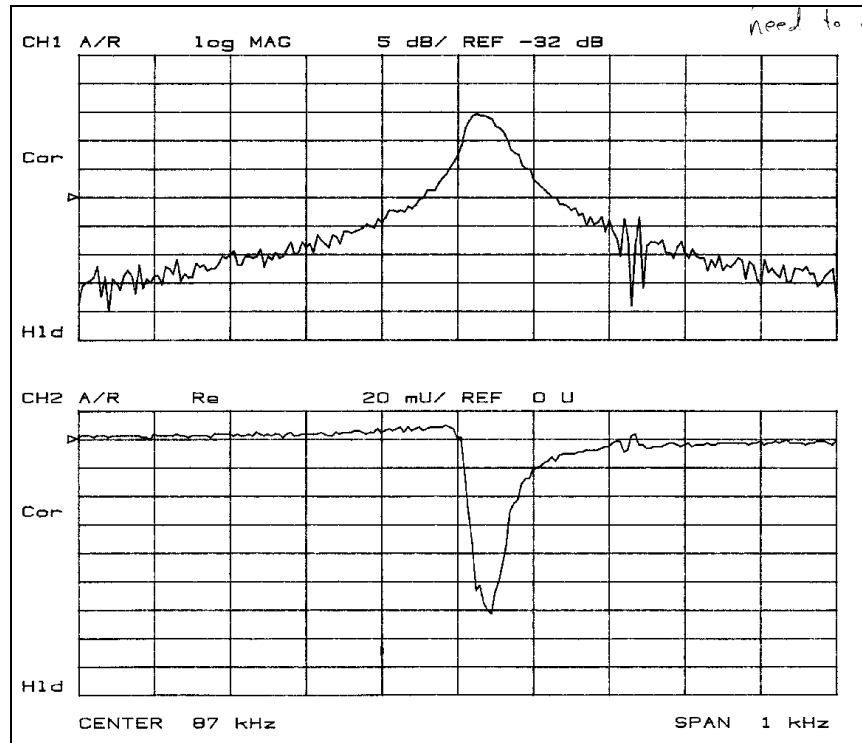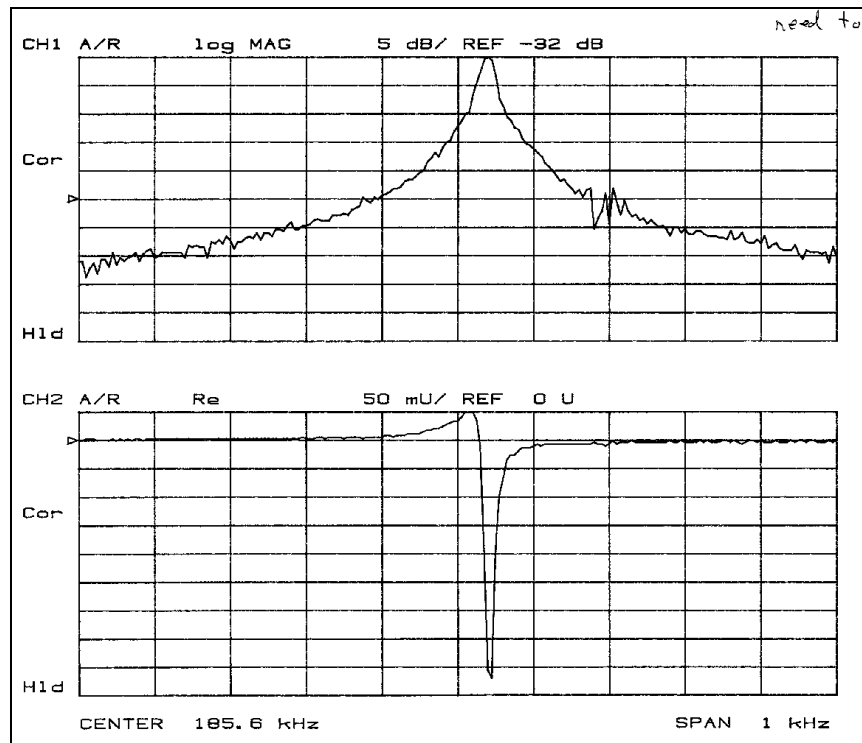
Figure 10. The beam transfer function response of the vertical damper system at the 1-Q line. There are 36 bunches at 21 mA. The multiplier settings are y1=0.0V and y2=5.0V
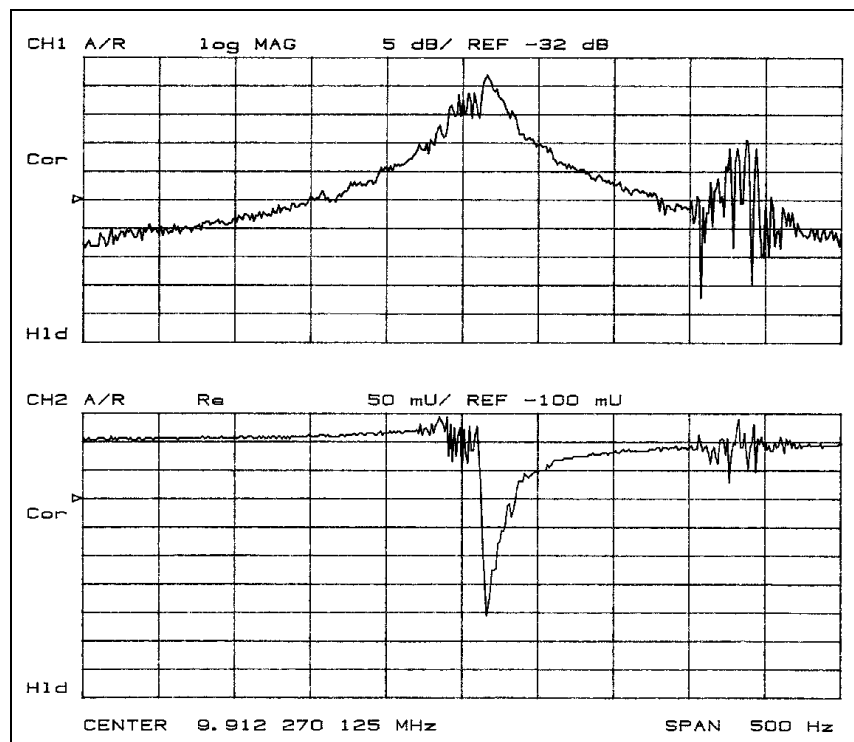

Figure 11. The beam transfer function response of the vertical damper system at the 1+Q line. There are 36 bunches at 21 mA. The multiplier settings are y1=0.0V and y2=5.0V

Figure 12. The BTF response of the horizontal damper system at the 73-Q line. There are 36 bunches at 40 mA. The multiplier settings are x1=8.5V and x2=3.0V
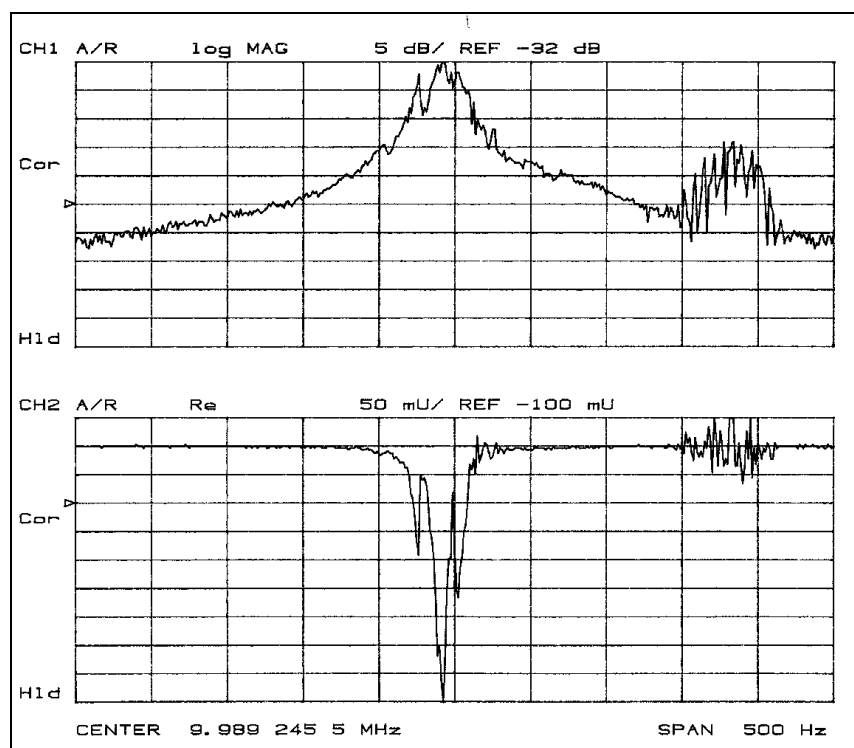

Figure 13. The BTF response of the horizontal damper system at the 73+Q line. There are 36 bunches at 40 mA. The multiplier settings are x1=8.5V and x2=3.0V
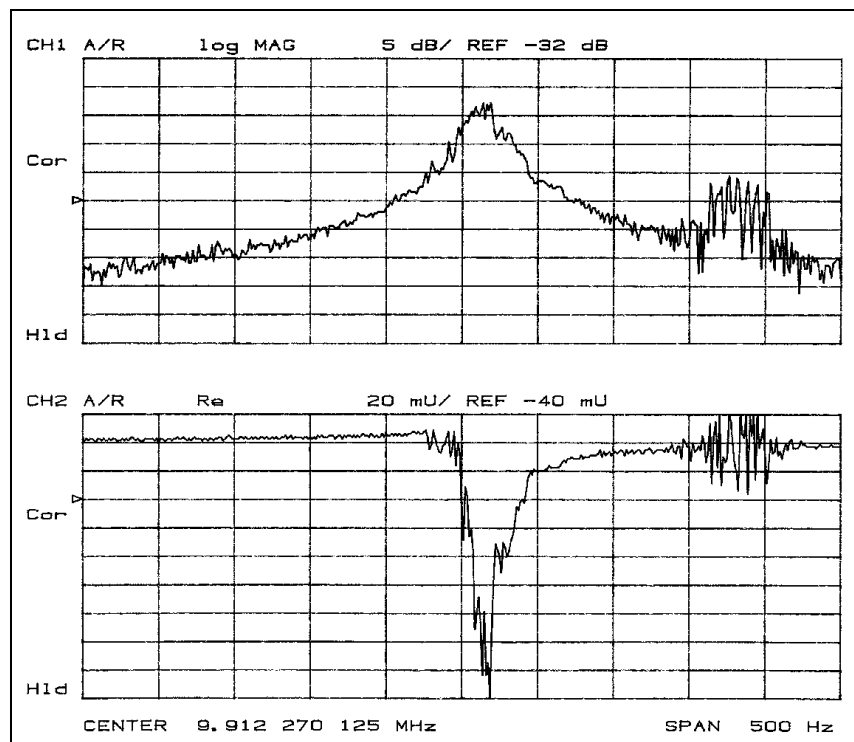
Figure 14. The BTF response of the horizontal damper system at the 73-Q line. There are 36 bunches at 40 mA. The multiplier settings are x1=5.0V and x2=2.5V
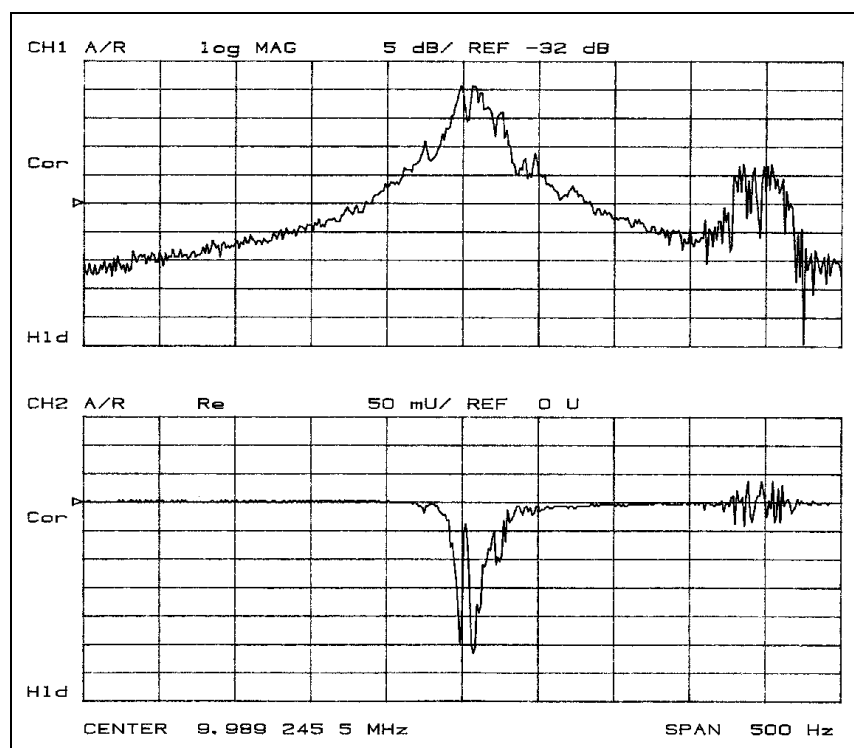

Figure 15. The BTF response of the horizontal damper system at the 73+Q line. There are 36 bunches at 40 mA. The multiplier settings are x1=5.0V and x2=2.5V